Renewable and Sustainable Energy Reviews 36 (2014) 428–439

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

# Microgrids in active network management—Part I: Hierarchical control, energy storage, virtual power plants, and market participation

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## ARTICLE INFO

*Article history:*
Received 19 August 2013
Received in revised form
5 December 2013
Accepted 4 January 2014
Available online 22 January 2014

*Keywords:*
Energy storage
Hierarchical control
IEC/ISO 62264 standards
Microgrid
Market structure
Virtual power plant

## ABSTRACT

The microgrid concept has been closely investigated and implemented by numerous experts worldwide. The first part of this paper describes the principles of microgrid design, considering the operational concepts and requirements arising from participation in active network management. Over the last several years, efforts to standardize microgrids have been made, and it is in terms of these advances that the current paper proposes the application of IEC/ISO 62264 standards to microgrids and Virtual Power Plants, along with a comprehensive review of microgrids, including advanced control techniques, energy storage systems, and market participation in both island and grid-connection operation. Finally, control techniques and the principles of energy-storage systems are summarized in a comprehensive flowchart.


**Contents**



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http://dx.doi.org/10.1016/j.rser.2014.01.016

**Nomenclature**

| | |
|---|---|
| CSI | current source inverter |
| DER | distributed energy resource |
| DG | distribution generation |
| DMS | distribution management system |
| ESS | energy storage system |
| FES | flywheel energy storage |
| LC | local control |
| LV | low voltage |
| MGs | microgrids |
| MGCC | microgrid central controller |
| MMS | microgrid management system |
| MPPT | maximum power point tracking |
| MSs | micro sources |
| PCC | point of common coupling |
| PI | proportional integral |
| P/Q | active and reactive power |
| PV | photovoltaic |
| RESs | renewable energy sources |
| SMES | superconducting magnetic energy storage |
| SOC | state of charge |
| UPS | uninterruptible power supply |
| VSC | voltage source converter |
| WT | wind turbine |

## 1. Introduction

Microgrids and virtual power plants (VPPs) are two LV distribution network concepts that can participate in active network management of a smart grid [1]. With the current growing demand for electrical energy [2], there is an increasing use of small-scale power sources to support specific groups of electrical loads [3]. The microgrids (MGs) are formed of various renewable sources of electrical energy, such as wind turbines [4–6] or photovoltaic cells [7–9] with storage (e.g., batteries or super capacitors) [10], which operate in either island mode or grid-connection mode [11,12]. Such implemented projects of MGs have demonstrated their efficiency in very different applications. Lidula et al. [13] presented some existing microgrid networks from North America, Europe, and Asia. Indeed, MGs have attracted great interest due to their tremendous application potential in remote areas, where power provision presents a challenge in terms of transmission or distribution [14].

There are three different classes of benefits associated with MGs: Technical, Economical and Environmental. In [15,16] some of the benefits are presented from a technical point view, such as supporting the power of remote communities, higher energy efficiency, the lack of vulnerability of large networks, and power blackouts reduction. The economic benefits have been reviewed comprehensively by Basu et al. [17], and consist of reductions in emissions, line losses, and interruption costs for the customer, minimization of fuel cost, ancillary services, etc. The environmental benefits of MGs are discussed in [18], out of which the following provides some samples: MGs may result in lower emissions of pollutants and greenhouse gases; the generation system, also requires a smaller physical footprint; MG usage can increase the number of clean energy sources incorporated into the grid; and it offers decreased reliance on external fuel sources.

The other main concept in the active distribution network is the VPP, which manages the energy of the system and is tasked with aggregating the capacity of distributed generation (DG), the Energy Storage System (ESS), and dispatchable loads (DLs) [19]. Indeed, the first idea for creating VPPs appeared in 1997 [20], and their modular structure is considered to be a great advantage [21].

Since future distribution networks will require completely novel smart-grid concepts [22], it is necessary to conceive of flexible MGs that are capable of intelligently operating in both grid-connected and island modes. As discussed by Zeng et al. [23], experts and researchers are currently working on simulation and modeling [24–26], the optimization of power quality [27], power management and stability [28], control of generation units and systems, and so on.

Over the last several years, researchers have been also working on attaining approval for standards for the most suitable overall MG design. In [29] a summary of the European and American standards applicable to MGs is presented. The IEEE 1547 and UL 1541 (in the US) standards are the most important guides for operation, design, and connection of distribution resources with electric power systems [13]. Indeed, there are no exact standards which have been developed for adapting MGs, but some Distributed Energy Resource (DER) standards can be adapted to them [29]. IEEE P1547.4 can be adapted for the connection of DERs and specifically it covers some topics missing from IEEE Std 1547, such as frequency, power quality, and the impact of voltage [30,31]. The other standards which can be adapted to MGs to cover low-voltage distortion and power quality interference are EN50160 and the IEC61000 [32–34].

In recent years, several control devices have also been developed for improving the integration of MGs in island and grid-connection modes. Therefore, the variation of power generation and interconnection, as well as the electrical interface between different sources, energy storage, and the main grid may be the barriers for achieving a common standard for connecting DERs to the grid [29].

In order to deal with the above issues, this paper proposes the IEC/ISO 62264 international standard to be applied to MGs and VPP, which are considered here from hierarchical control, energy storage, and marketing perspectives. The objective of IEC/ISO 62264 is to offer consistent terminology for supplier and manufacturer communications, and to thus serve as a foundation for clarifying applications and information. The standard can be explained at five levels: *level zero* (the generation process), *level one* (the process of sensing and adjusting generation), *level two* (monitoring and supervising), *level three* (maintaining and optimizing), and *level four* (market structure and business model) [35,36]. Fig. 1 illustrates the adaptation of the standards to MGs. The present paper includes a comprehensive literature survey to provide information on the detailed status of advances in MG principles from the viewpoints of both island and grid connected mode of operation, on the basis of the proposed standard. The MG control hierarchy is discussed in Section 2. Energy storage issues and the microgrid market structure are discussed in Sections 3 and 4, respectively. The virtual power plant hierarchical controls are discussed in Section 5. The literature survey concludes in Section 6.

## 2. Microgrid control principle

As a result of the recent widespread application of power-electronics devices [37], the operation of an MG requires both energy management and the classification of a control strategy. Power flow control, resynchronization between the MG and the

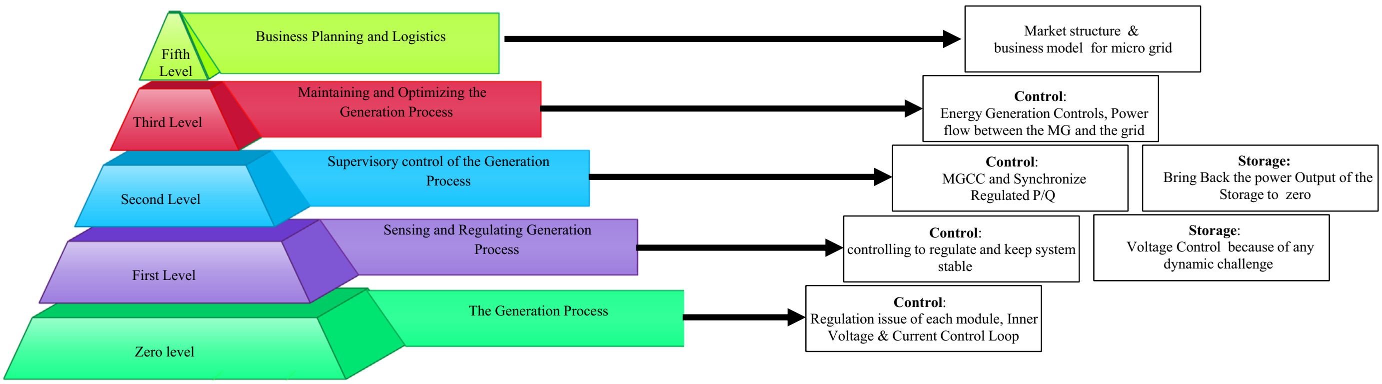



**Fig. 1.** IEC/ISA 62264 std. levels and applied in microgrid context.

main grid, adjustments of voltage and frequency in both modes, and improvements to MG efficiency together comprise the key principles of MG control structure [38,39]. The Union for the Coordination of Transmission of Electricity (UCTE) in continental Europe has defined a hierarchical control for large power systems, presented in [36]. The most suitable control design should certainly cover all the responsibilities of MG controllers, which [40] defined thus: the system should function at predefined operating points, or within satisfactory operating limits; active and reactive power must be transferred by optimal means; system stability should be maintained; processes of disconnection and reconnection should run seamlessly; local Micro sources (MS) production should be optimized for best market participation and power exchanges with the utility; loads must be classified according to sensitivity, from highest to lowest (e.g. medical equipment is the highest priority consumer); if a general failure occurs, the MG should be able to operate through a black start; and finally, ESS should support the MG and increase the system′s reliability and efficiency. Justo et al. [41] investigate some different energy management and control strategies of the MG system which are published relying on the most current research works.

With respect to the above-mentioned requirement, and based on the IEC/ISO 62264 standard, microgrid hierarchical controls are defined on four levels (*zero to three*), which also are shown in Fig. 1. Level zero is the inner control loop for controlling the output voltage and current from the sources. The reference value for the inner control loop is generated by primary control (*level one*). Then, secondary control in the next step monitors and supervises the system with different methods. Finally, the last level is tertiary control which manages the power follow and interface between the MG and main network. In the rest of this paper, the four levels above the control level are discussed.

### 2.1. Internal control loop

The target of this control level (*level zero of the IE/ISO 62264 std.*) is to manage the power of MSs. Generally, the first step of the MG control is the source operating point control, using power electronic devices in current or voltage control modes [38]. The purpose of the power electronic interface in voltage control mode is to manage frequency and voltage inside the microgrid while the system is connected to energy storage devices (island mode) [42]. On the other hand, in current control mode, where the system is often joined to the main grid (grid connection mode) [43], management of the active and reactive power is the main target [36,44]. Indeed, the inner control loop for wind and solar power which are most common Renewable Energy Sources (RESs), is in practice created by the power converter. For instance, a Doubly-Fed Induction-Generator (DFIG) wind turbine consists of two AC/DC (rotor side) and DC/AC (grid side) converters with a DC-link that can either inject or absorb power from the grid, actively controlling voltage [45]. The responsibility of the rotor side is to optimize power generation from the source, while providing control of active and reactive power and maintaining the DC link voltage is the duty of the grid-side converter [46–49]. Moreover, based on the hardware structure of the PV system, after the PV module and MPPT, the system includes dc–dc converters and inverters, whose responsibility is to create the optimum conditions to support the normal customer load in island mode, or to send power into the network in grid-connection mode [49].

The optimization and inner controls need to have accurate reference values for the frequency and voltage amplitude, and this is the duty of the primary control.

### 2.2. Primary control

As aforementioned, the target of this control level (*level one of IEC/ISO 62264 std.*) is to adjust the frequency and amplitude of the voltage references that are fed to the inner current and voltage control loops. The primary control should have the fastest response to any variation in the sources or the demand (on the order of milliseconds) [50], which can help to increase the power system stability. Furthermore, the primary control can be used to balance energy between the DG units and the energy storage elements, such as batteries. In this situation, depending on the batteries′ state of charge (SoC), the contribution of active power can be adjusted in line with the availability of energy from each DG unit [51]. In other words, to achieve optimal performance of the primary control, especially in island mode, it is necessary to control the SoC [52]—an idea that will be developed further in Section 4. A complete and extensive review and technical investigation into the control strategy and hierarchy is provided by Guerrero et al. [53] and Bidram and Davoudi [38].

The DG power converter control techniques in ac MGs are classified into two different methods: grid-following and grid-forming [54,55]. Grid-forming converters are voltage-control based and an equivalent circuit for them includes a voltage source and series low impedance. Creating a reference value for voltage and frequency by using a proper control loop is the duty of this type of power converter [54]. On the other hand, grid-following power converters are designed as control-based and can be represented by a current source with high parallel impedance. In addition, power delivery to the main network in grid-connection mode is the responsibility of the grid-following power converter [56]. It should be noted here that one of the power converters in island mode must be of the grid-forming model in order to determine the voltage reference value. In other words, a grid-following converter cannot control the MG in island mode.

The differences between these connections are shown in Fig. 2. A comprehensive review of primary control in grid-forming strategies is presented by Vandoorn et al. [57]; grid-following techniques are discussed by Rocabert et al. [58] and Blaabjerg et al. [49].

#### 2.2.1. Droop control and active load sharing

The main idea of the primary control level is to mimic the behavior of a synchronous generator by reducing the frequency when the active power increases [59]. This principle can be applied to Voltage Source Converters (VSCs) by employing the well-known *P*/*Q* droop method [60]. The principle of the droop control method for MGs is the same as that for an equivalent circuit of a VSC connected to an AC bus (Fig. 2) [38]. On the other hand, the principle of active load sharing involves using a parallel converter configuration based on a communication link [61,62]. The accretion of voltage regulation and power sharing in the control methods based on a communication link is better than with droop control methods. However, over long distances, communication lines are vulnerable and expensive [57]. There are some different methods based on communication links which researchers have proposed, such as concentrated control [63,64], master/slave [65,66], instantaneous current sharing [67,68], and circular chain control methods [69].

Since a communication link is not necessary for droop control, it is more reliable than active load sharing, However, the method does have certain drawbacks [53,70,71]: it is one-dimensional and can only support one control objective; In an LV distribution line, there is resistive effective impedance between the power electronic devices and the AC bus, so the phase difference is zero, meaning that it is not possible to apply the frequency and voltage droop characteristics to determine the desired voltage references; since voltage in MGs is not found to the same exact degree as frequency, reactive power control may negatively affect the voltage adjustment for critical loads; the conventional droop method cannot differentiate between load current harmonics and circulating current in nonlinear loads; and the droop method has its load-dependent frequency and amplitude deviations. A number of researchers have attempted to propose different solutions to these issues, such as load sharing and voltage and frequency regulation tradeoffs [57], line impedance [72], virtual frame transformation [73–75], coupling inductance [76–78], etc. The ideas are extensively discussed in [38], and [29] along with their advantages and disadvantages.

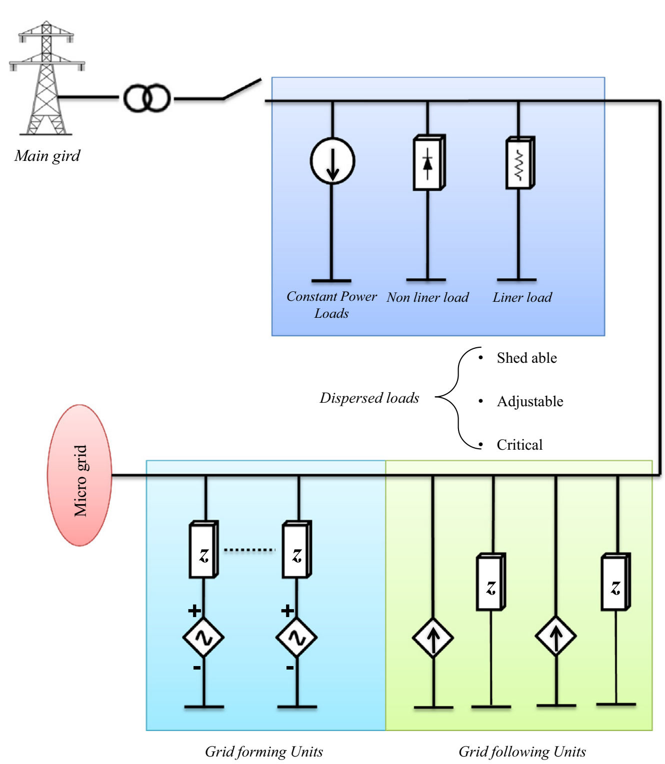



**Fig. 2.** Equivalent circuit diagram of converters connected to MG.

The droop is based on voltage-reactive power and frequency-active power controls (*P–f, Q–V*) in high voltage (HV) and medium voltage (MV) systems, a description of which is given in Fig. 3 [79,80]. The figure illustrates that the operational voltage is regulated by a local voltage set-point value, taking into account the inductive and capacitive reactive current generated by the suppliers. In inductive situations, voltage operation increases, and in order to adjust this, the voltage set-point must decrease. In capacitive mode, however, the set-point value increases. The limitations of the reactive current variability are based on the maximum reactive power [40,81,82].

In low voltage (LV) systems, however, the circuit is more resistive and so the droop control should be based on active power–voltage and reactive power–frequency (*P–V, Q–f*) [73,83] If MG sources are to conform to IEEE Standard 1547–2003 [84], then a mechanism should be in place to restore the system frequency and voltage to nominal values following a load change [85,86]. As in the case of the electrical power system controls, this restoration mechanism is referred to as *secondary control* of voltage and frequency.

### 2.3. Secondary control

The hierarchical control system – in particular, the secondary control section (*second level of IEC/ISO 62264 std.*) – works to compensate for voltage and frequency errors and to regulate the value in the operational limitations of the microgrid. In other words, the secondary control ensures that the frequency and voltage deviations are regulated toward zero following each load or generation change in the MG. The secondary control serves power systems by correcting the grid-frequency deviations within allowable limits, for example by $\pm 0.1$ Hz in Nordel (North of Europe) or $\pm 0.2$ Hz in UCTE (Continental Europe) [36]. The response speed of the secondary control is slower than the first control level because of some limitations, such as availability of primary sources and battery capacity [58]. This control level can be divided into centralized [87] and decentralized controls [53]. By far the largest body of research and work on decentralized MG control has been performed by [88]. Additionally, novel general approaches to centralized control base on droop control and decentralized control based on communication links is presented by Guerrero et al. [36] and shafiee et al. [89], respectively.

#### 2.3.1. Centralized control

The microgrid controllers in centralized control are based on principles similar those of the inner loop controllers explained in the previous part. A Microgrid Central Controller (MGCC) is available for each microgrid to interface with the Distribution Management System (DMS). Indeed, the definition of centralization or decentralization is based on the position of the MGCC. This type of control is very suitable for certain small manually controlled MGs, as well as for MGs with common goals and those pursuing cooperation [40].

#### 2.3.2. Decentralized control

The main duty of decentralized control is to specify the maximum power generated by MSs, while at the same time taking into account the microgrid's capability to support the consumer

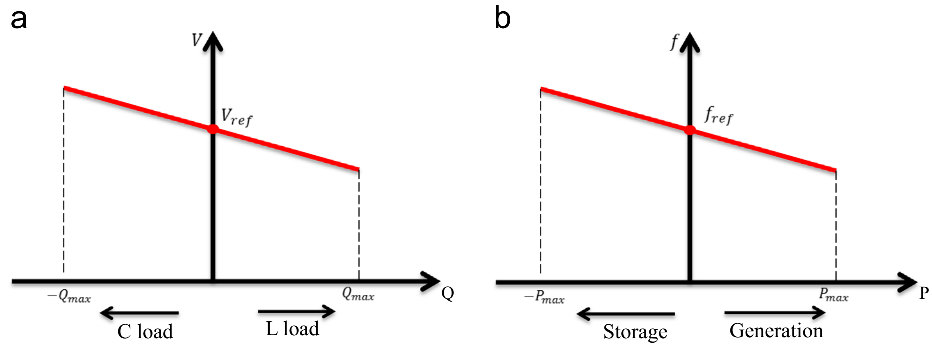



**Fig. 3.** Voltage and frequency versus active and reactive power.

and increasing power exports to the grid for market participation. This type of control is ideally utilized in the MGs of different suppliers, where there is a need to make decisions separately regarding individual situations, and for MGs with active roles in an electrical market environment—such MGs should possess an intelligent control for each unit, in addition to MSs with responsibilities other than power generation [40].

In order to connect a MG to the grid, the frequency and voltage of the grid must be measured. These values will serve as references for the secondary control loop. In the case of MG controls, this restoration of references is the duty of the tertiary control. Indeed, the phase angle between the grid and MG will be synchronized by means of a synchronization control loop, which is disabled in the absence of the grid.

### 2.4. Tertiary control

The purpose of this control level (*level three of IEC/ISO 62264 std.*) is to manage the power flow by regulating the voltage and frequency when the MG is in grid-connected mode. By measuring the *P*/*Q* through the PCC, the grid's active and reactive power may be compared against the desired reference. Hence, grid active power can be controlled by adjusting the MG's reference frequency. This control level is the last and slowest level of control, and ensures optimal operation of the microgrid, not only technically, but also economically [38]. Technically, if a fault or any non-plane islanding issue arises for the MG, then the tertiary control will attempt to absorb *P* from the grid in such a way that, if the grid is not present, the frequency will begin to decrease. When the expected value is surpassed, the MG will be disconnected from the grid for safety, and the tertiary control disabled [53]. Islanding detection is also a very important issue in disconnecting the MG from the main grid in tertiary control, and this is discussed in the second part of this paper.

### 2.5. Discussion of the hierarchical control of microgrids

Advanced microgrid control techniques under the IEC/ISO 62264 standard are summarized by the flowchart in Fig. 4. As discussed in this section, and based on the proposed standard, to achieve the optimum level of adjustment of the operational reference value, the control of the MG can be divided into four different levels. The foundational control level is the inner control loop: active and reactive power management inside the sources and control of voltage in the DC-link are its responsibility. Additionally, the inner control loop is implemented by fast voltage and current control loops. An accurate reference value for voltage and frequency for control of the power converters can be obtained through primary control by different methods. In the next step, there are two different approaches to secondary control: grid connection and island mode. During grid-connection mode, the microgrid operates based on active and reactive power controls, whereas in island operation, the secondary control acts as voltage and frequency based. As shown in Fig. 4, the reference value for sending the deviation of voltage and frequency to the primary control are determined basing on the variation of active and reactive power received from the main network. Power management and the reinstatement of the secondary control is the objective of the tertiary control level. Moreover, optimizing the set-point operation of the system from both technical and economic points view is the other objective of the last level of control in the MG.

## 3. Principle of the energy storage system

Managing power balance and stability is a challenging task, as these depend on a number of variables. Energy storage plays a crucial role in mitigating the problem [8]. In fact, by combining energy storage with renewable power generators, output power may be stabilized by storing surplus energy during periods of high obtainability, and dispatching it in case of power shortage [90]. As mentioned earlier in this paper, the principles of MG are almost the same in both island and grid-connection modes. There are, however, some fundamental contradictions between the two modes in terms of storage systems. Frequency regulation, the integration with renewable energy production, and the large capacity for power density and energy are the main applications of a storage system in grid-connection mode. However, enhancing power quality, stability, and quick response times to transient faults are the main responsibilities of a storage system when the microgrid is working in island mode [91]. Another classification of energy storage in the microgrid is based on the arrangement of the storage system, which may be aggregated or distributed. The aggregated model has the same principles as the master unit, and the microgrid is supported with a central energy-storage system that, depending on the microgrid arrangement can be connected to the DC bus or may combine with a power electronic interface and connect to the AC bus [92]. This model is very popular for MGs with small scale and low-level generation and demand. On the other hand, in the distributed arrangement, the energy storage system is connected to the renewable energy sources via different and individual power electronic interfaces. In this model, each storage system has responsibility for the control and optimization of the power output of the sources to which it is connected. The intercommunity of the transmission line in the power trade-off between energy storage and MG is a disadvantage of the system [93,94].

One objective of this paper is to adapt the energy storage systems in MG to IEC/ISO 62264 standards, which is discussed as below along with a briefly investigating on the different applications and techniques of storage systems in MG.

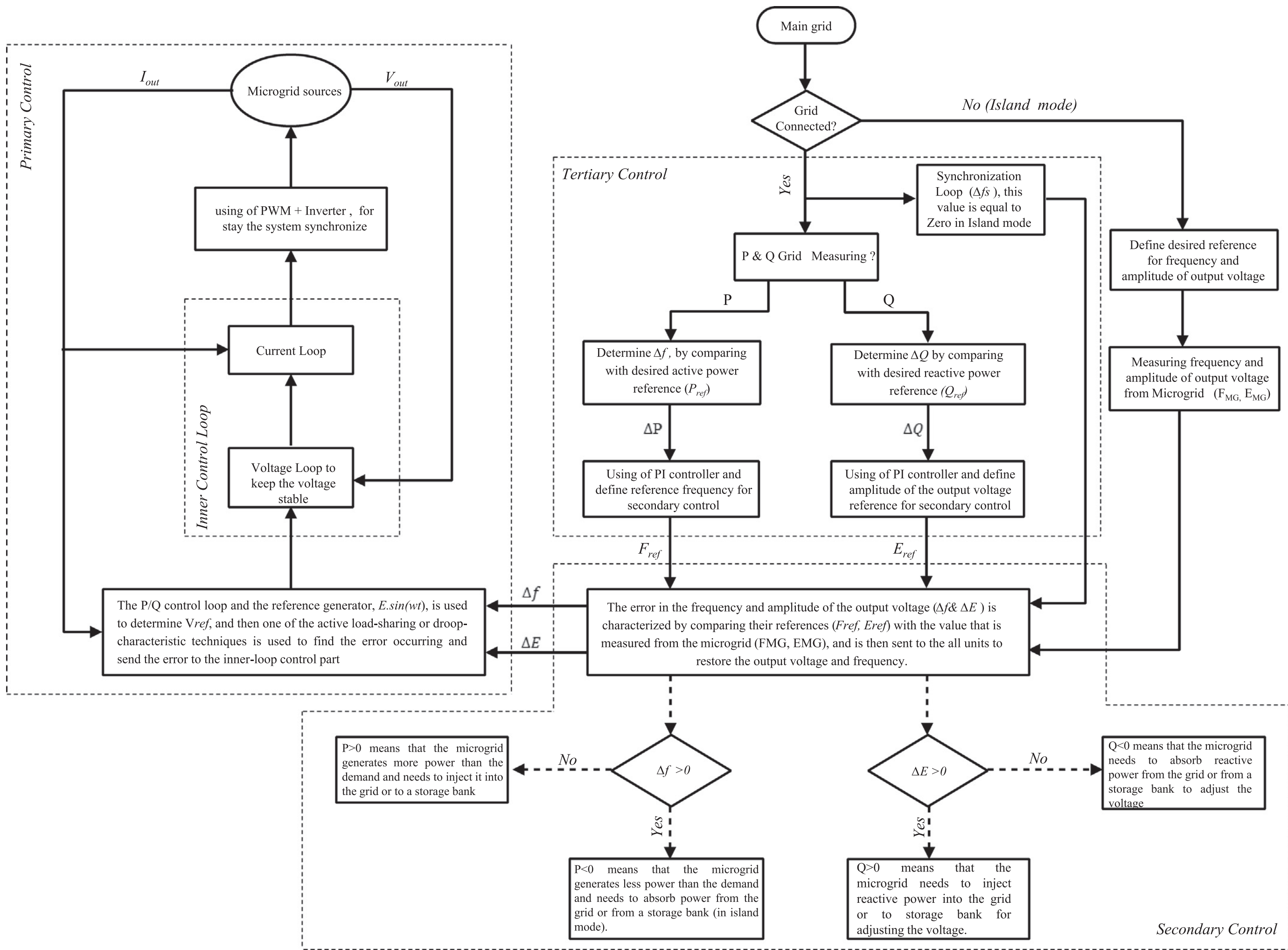



**Fig. 4.** Hierarchical control of microgrid based on IEC/ISO 62264.

### 3.1. Application of energy storage in microgrid

An ESS functions like a power-quality regulator in order to yield a specified active or reactive power to customers. The principle of voltage control, which classifies loads by priority and employs load shedding, is not suitable for achieving high power quality impact in a MG. Hence, another benefit of ESSs may be that they result in improved power quality in the MG [95,96]. Moreover, there are different applications that can be provided with energy storage systems, such as black start [97,98], power oscillation damping [99,100], grid inertial response [101], wind power gradient reduction [102], peak shaving [103,104], and load following [105]. Rabiee et al. [106] present a comprehensive review of these applications with wind turbines. Researchers have also recently been endeavoring to come up with various techniques for improving power management and system stabilization of MGs by using ESS. Microgrid storage systems and the power electronic interfaces for linking sources are discussed in [107]. In [108], MG cooperative control methods for island operation are discussed with respect to control over frequency and voltage, as is a control system for decreasing power variation from RESs (such as wind turbines). ESS can also help to stabilize frequency in very large power systems. The influence of electromechanical oscillations on the rapid response of energy storage in a power system is indicated by Mercier et al. [109] and Kim et al. [110].

### 3.2. Standardization of energy storage system

According to the IEC/ISO 62264 standard, MG hierarchical control configuration falls into the three categories described previously. As the third level is labeled as a connection element in the main grid, and the storage system is based on island mode, storage control does not contain tertiary controls, but rather consists of a secondary and primary level. The secondary level is the centralized control, referred to as the master unit or Microgrid Management System (MMS) [111], and like the control hierarchy, the primary level consists of a local control. Primary control monitors the frequency and determines the surplus or shortage of power. Supervisory control of MS and ESS is the responsibility of the secondary control level [112]. Fig. 5 shows the hierarchical control of energy storage [108]. Owing to its quick response to fluctuations, energy storage is a significant element in MGs, particularly in island mode. Sustaining the MG's frequency and voltage through a storage system takes milliseconds, while the response times of diesel generators, fuel cells, or gas engines is very slow in comparison.

Just like the main responsibility mentioned in the preceding section, power balancing for the regulation of frequency and voltage in a storage element of an island-mode MG is also related to the control level. Nevertheless, due to restrictions in establishing equilibrium between generated and consumed power as a

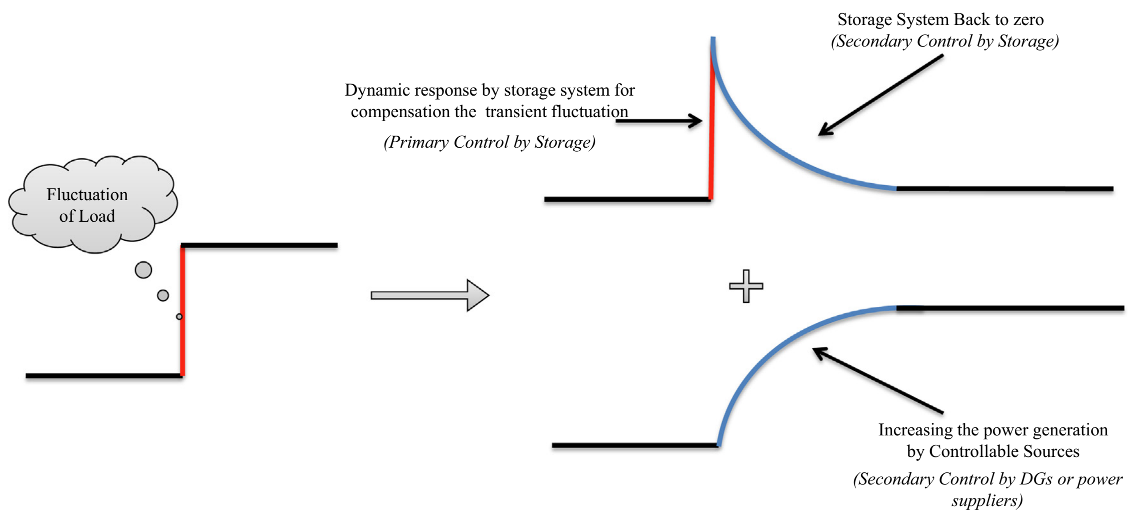



**Fig. 5.** Hierarchical control responsibility in ESS [108].

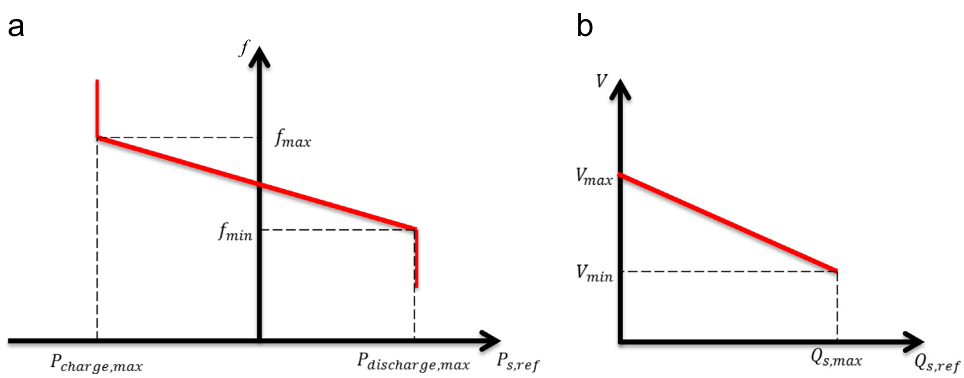



**Fig. 6.** Frequency and voltage versus active and reactive power.

result of the system capacity on hand, the storage system's output power must be returned to zero as quickly as possible, and this is the duty of the secondary control [108].

#### 3.2.1. *Primary control in energy storage systems*

Controlling the active power in the MG is the responsibility of the storage system, which must monitor it continually. Based on the first level of the IEC/ISO 62264 standard, the network power capability can sense the active power by detecting frequency variations. When the system frequency increases ($f$ is near $f_{max}$), this means that the power being generated is greater than the demand, and there is a need for surplus energy to be absorbed by the storage system, which is allowed by its current state of charge (SoC) to control the active power. With an increase in demand, the capacity of the system begins to reduce, which may be reasonable if the system frequency is much higher than the minimum frequency ($f_{min}$). However, when the frequency approaches the minimum frequency ($f_{min}$) for any reason (such as increasing demand), the storage system must begin to inject power into the system to obtain the most stable condition and improvements in power quality [113]. The characteristic variation is formulated in [114].

In Fig. 6, a storage system control using (a) frequency versus active power and (b) voltage versus reactive power droop characteristics is shown. The performance of reactive power sharing depends on the impedance of the connection line between the storage system and the network.

Hence, controlling the network with reactive power is not the optimal method; it would be better to set the reactive power value to zero in the storage charging process. In this situation, storage charging begins if there is excessive generation capacity, or if there is low demand [113].

#### 3.2.2. *Secondary control in energy storage systems*

The ESS operation may fail if only the ESS is involved in stabilizing the microgrid. Load-sharing of the burden of the ESS and the DG units′ output power is a requirement for preventing such an outcome [52]. As illustrated in Fig. 6, the power output set-point of each MS should be calculated and dispatched through the secondary control function, First, based on the IEC/ISO 62264 standards; the responsibility of the secondary control in storage system is monitoring the system fluctuation. Then, after compensating the power variation by primary control in storage and increase the power generation, the secondary control bring the power output of the ESS back to zero. As mentioned in Section 2, it is the local controls that are ultimately responsible for regulating the power output locally in each component, while the secondary control compares the measured power output of the storage system with the reference value in order to obtain the error. The total required power for charge and discharge are obtained with this error (Fig. 4) [108,113].

### 3.3. *Techniques of energy storage systems*

Storage of energy can be achieved by converting electrical energy into another form, such as chemical or mechanical energy

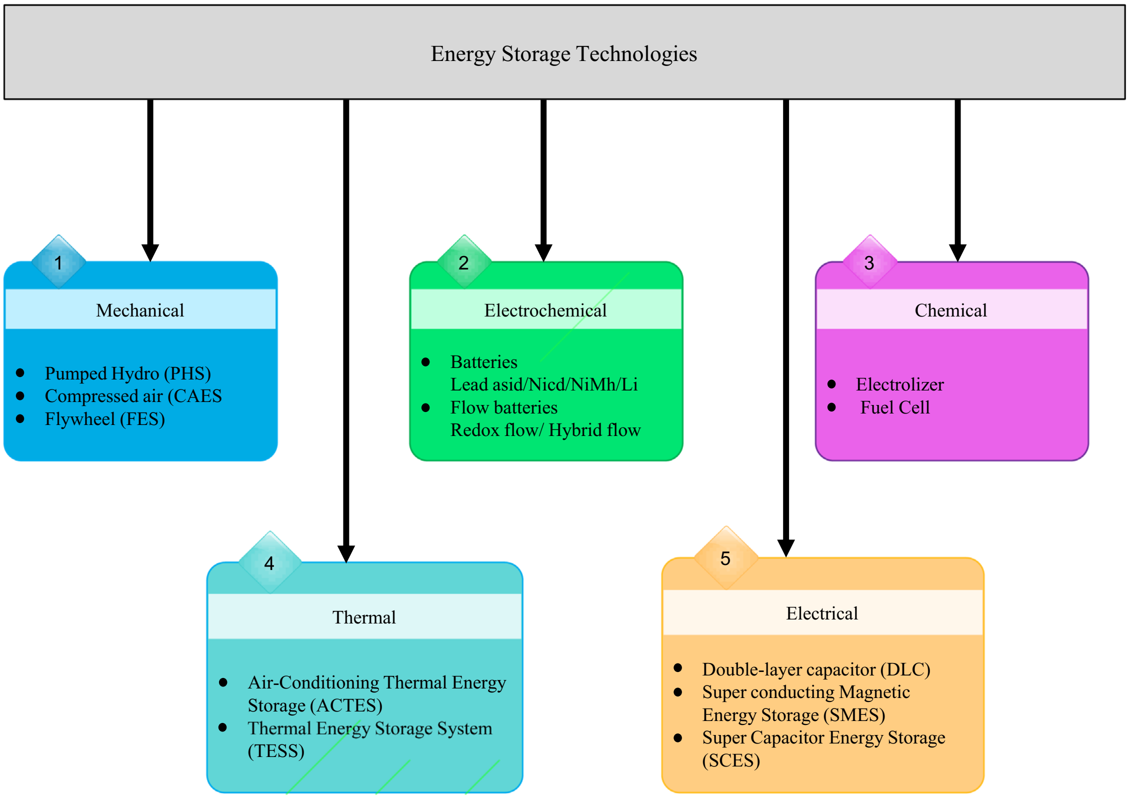



**Fig. 7.** Different techniques for energy storing.

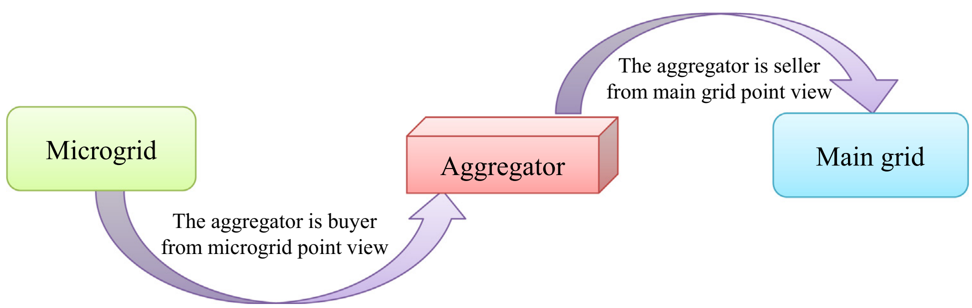



**Fig. 8.** Role of the aggregator in the market participation.

which a complete classification of ESS types is presented in Fig. 7. In recent years, advanced energy storage technologies have been investigated by researchers, which have presented a comprehensive review by Tan et al. [93] and Akhil et al. [95].

Electrochemical storage technologies (or batteries) are the largest storage group and were investigated by Yang et al. [115] and Divya et al. [116]. Batteries are an advanced technique for storing electrical energy in electrochemical form. They exist in a number of different technologies, including lead-acid [117,118], Nickel-Cadmium (NiCd) [119], Nickel-Metal Hydride (NiMh) [120,121], and Lithium-ion [122]. The lead-acid battery is the most economic option for microgrids, especially for larger systems [116]. The main advantage of this storage technique is that it can be constructed in a wide range of different sizes (from 100 W to several MW), and for this reason it is very popular for microgrid implementation.

Flywheel Energy Storage (FES) is a technique for storing electrical energy in the mechanical energy of a spinning rotor. These are divided into two types: low speed and high speed. Generally, flywheels with speeds of under 10,000 rpm are considered low-speed, and these are much more popular in industry [123–125].

Electric double-layer capacitors can serve as another method of storing electrical energy, in this case between two conductor plates directly and without chemical processing. Such a storage systems can rapidly react to support a MG in a transient condition.

Electrical energy can also be stored in the magnetic field created by the DC flow of a superconducting coil—a storage method called Superconducting Magnetic Energy Storage (SMES). The method is increasing in popularity for MGs, due to the flexibility it offers in exchanging active and reactive power. Moreover, the charging and discharging processes occur rapidly with this technique. For these two reasons, the SMES method is suitable for improving power quality [126].

Pumped-storage hydroelectricity can be used to store excess electrical energy by pumping a large volume of water to an upper level. Under the electricity shortage conditions, water can be converted to electricity using turbine and generator. The infinite technical lifetime of the technique is its main advantage [127]. Compressed air energy storage (CAES) is a method in which

electrical energy is used to compress air to a pressure of around 70 bar. The CAES method is very expensive, and is only economic when large volumes of cheap natural storage are available—such as are provided by salt caverns, aquifers, and caverns in hard rock. The compressed air is converted to electrical energy using an expansion turbine and generator [124]. Following Fig. 7, the next storage methods are thermal and chemical techniques. Storage of electrical energy as heat in water tanks is the principle of thermal storage. Under the rubric of chemical methods of electrical storages include fuel cells, electrolysers, and hydrogen tanks [93].

## 4. Market participation

Recently, with the appearance of the smart grid and the increasing motivation for the use of MGs, marketing seems a more significant issue than ever. It was stated in the introduction section that the last level of the IEC/ISO 62264 standard concerns the business model and market structure. As mentioned in [128], there are in general three main transactional models, the first of which is known as the pool. This method is based on centralized marketing, in which all power suppliers inject their own production, as well as the price of generation, into the pool, and customers then submit their demand to the same pool in order to make a deal. A significant aspect of all marketing models is the Independent System Operator (ISO), whose main objective is not generation dispatch, but rather matching energy supply to demand in order to ensure reliable system operation. ISO systems in the pool method usually receive bids based on the demand forecasted for the following day. With this strategy, their consumers are supported with the lowest electricity price, and the optimal price for generation is received. There are three types of ISO power pool:

- Tight power: This method's function usually is based on bounding a control area through metering and interconnection;
- Loose power: Unlike with tight power, there are no control area services in loose power pools. Supporting for consumers is only during emergency conditions;
- Affiliate power pools: The power generation and the energy demand of the consumer cooperate as a single utility by using an aggregator.

A bilateral contract, or direct access, is the second transactional model. This method can be adapted well to MG conditions, because energy buyers and sellers can have electricity marketing directly without a connector system. The third model is a combination of the first two, and is the most complete method as it uses all the features of the pool and the bilateral method together. In this model, customers can select pool power generation first, and on this basis sign a bilateral contract. Moreover, marketing options can be very flexible in the hybrid system, which means there are many different prices based on different services and power quality [128].

### 4.1. Microgrids in power market competition

The section on storage indicated that a MG can participate in the energy market, like in ancillary service markets. The oligopolistic method, based on a multi-agent system, is the best market structure for MGs [17,129]. The authors of [130] and [131] present a comprehensive review of the implementation of multi-agent systems based on the technical challenges, approaches, and defining concepts, as well as the standards and tools. A market-based, multi-agent system framework for MGs is presented in [132,133]. MG agents are divided into production, consumption, power system, and MGCC agents [17,134]. As mention in Section 3 of this paper, microgrid control and energy management is the main responsibility of the MGCC, which must also coordinate the priority of loads. The MGCC, along with the consumption agent, participate directly in the marketing operation. Moreover, the power system agent is one of the most effective components for determining the buying and selling price for electricity, but does not itself participate in marketing operations. Microgrids buy and sell the shortage or surplus of power to or from a main grid through an aggregator. Therefore, the MG and main grid have different perspectives to the aggregator. For instance, during the selling of power by the MG to main grid, the aggregator is the seller from the point of view of the main grid, and is the buyer from the perspective of the MG (Fig. 8) [135].

Aggregators take care of local distribution systems and greatly reduce the workload burdens on both ISO and the local Distribution Network Operator (DNO), particularly when there are great numbers of retail market participants in the networks. In recent years, many proposals have been provided to change power transactions, of which retail wheeling is one. The main target of the method is to produce a market strategy for reducing the cost of electrical energy. A simple description of it is that electrical suppliers and customers can perform transactions remotely. Moreover, excess power is injected into the utility through the microgrid in open competition [128].

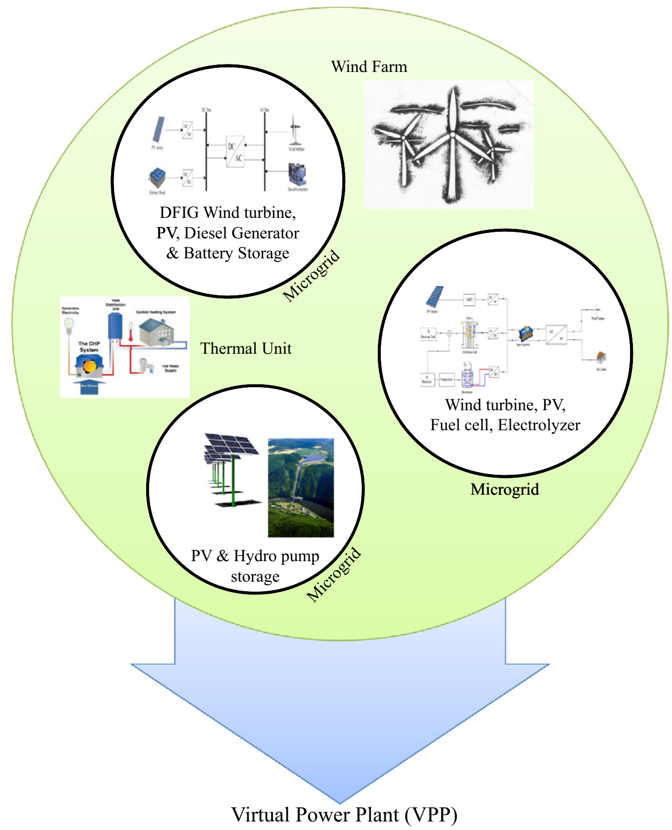



**Fig. 9.** Concept of VPP.

## 5. Virtual power plant

As mentioned in the introduction, MGs and virtual power plants (VPPs) are two concepts of the LV distribution network that can participate in active network management as a smart grid. The VPP is an energy management system tasked with aggregating the capacity of a number of DGs, ESSs, and dispatchable loads, as is

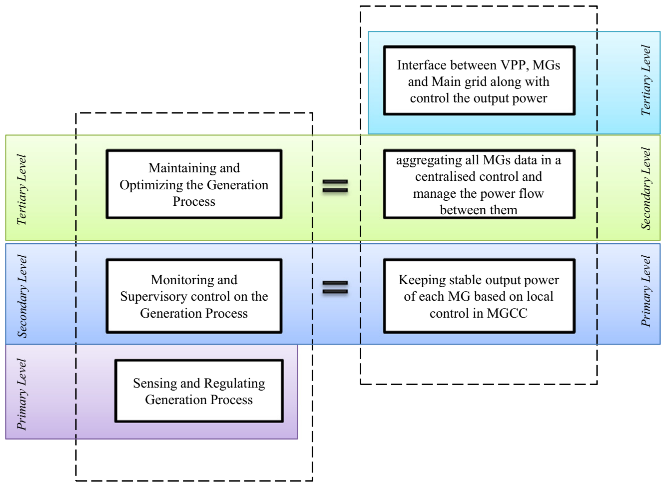



**Fig. 10.** Microgrid Vs VPP under IEC/ISA 62264 std.

discussed by Pudjianto et al. [19]. Fig. 9 shows the concept of the VPP, which is based on providing centralized control for multiple MGs, DERs, and loads.

VPPs are divided into two different types: commercial and technical. Commercial VPPs have a competitive participation in the electricity market and try to optimize the relation between generation and demand without respect to network limitations. Technical VPPs, on the other hand, try to optimize control and coordination, as well as system operation. To cover the two categories, there are three different approaches that can be used [136]:

- Centralized Controlled Virtual Power Plant (CCVPP)
- Distributed Controlled Virtual Power Plant (DCVPP)
- Fully Distributed Controlled Virtual Power Plant (FDCVPP)

The Smart Grid, Fenix, and Ecogrid projects are the most important European projects using the concept of the VPP and integrated DER [137].

VPPs must always be connected to the main grid and do not have the capacity to work in island mode [138]. Hence, in adapting VPPs to the IEC/ISO 62264 standards, all their control levels are always enabled—unlike in MGs, where the third control level is sometimes disabled. However, there are some different responsibilities in controlling MGs based on the standard level, compared with VPPs. These differences are shown in Fig. 10. The level zero of the standard in VPP is similar to the grid-connection mode of DG units.

The primary control role is the same as the secondary control level in the MG, while the secondary control level tries to optimize the inside of the MG. The tertiary control in VPPs has two levels: the lower level controls the interface between the VPPs and the utility network through the signal sent from the VPPs to the MG, while the upper level handles the control signal from the DNO to the VPPS [138].

## 6. Future trends and conclusion

Active distribution networks, MGs, and VPPs will become increasingly popular because of the trend toward increasing renewable energy sources. This paper proposed the IEC/ISO 62264 standard for adapting the hierarchical control and energy storage system in MGs and VPPs. To demonstrate the possibility of adapting the standard, a comprehensive review of hierarchical control, storage, and marketing principles, along with the VPP, is presented in this paper. The control strategy of MGs and VPPs is based on the standard of four different levels (*zero to third*).

Power converters in MGs operate on the basis of voltage and frequency in island mode and of active and reactive power in grid-connection mode. Hence, providing accurate reference values for the primary control is the responsibility of secondary and tertiary control levels. Therefore, due to the high accuracy of communication technique, the control method based on communication interfaces in the secondary control and intelligent agents in the tertiary control to optimize references is an extremely interesting area for future research. Adapting VPPs to the IEC/ISO 62264 standard is analogous to a microgrid but shifted a level up. In future research, the short-term scheduling of VPP operations may be a fruitful research area.

In addition, the standardization of the storage system on the basis of the proposed standard, following the loss of network connections in level three, consists of two levels (*primary and secondary*). Since in smart grid infrastructure ESS technology will play a significant role, hybrid-energy storage systems are among the most popular research proposals aimed at achieving the goal of smart storage.

Finally, in the last level of the standard, microgrids have shown the potential to provide ancillary services. An implementable market structure and business models for ancillary services provided by microgrids may also be a very interesting research area for the future.

## Acknowledgments

The authors would like to acknowledge the financial support provided by the Finnish Funding Agency for Technology and Innovation, Tekes, to the Smart Grids and Energy Markets (SGEM) research program.

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